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Designing and Fabrication of Intercooler and Control of Three Phase Digitalized Reciprocating Air Compressor Test Rig with Automatic Control Drive Unit

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Abstract

Air Compressors are used to raise the pressure of air with the minimum expenditure of energy. An air-compressor sucks the air from the atmosphere, compresses it and delivers the same under high pressure to a storage tank. Since the compression of air requires some work to be done on it, some form of prime mover must drive a compressor.The compressed air is used for many purposes such as for operating pneumatic drills, rivets, road drills, paint spraying, air motors and in starting and supercharging of I.C. Engines etc. It is also utilized in the operation of lifts, rams, pumps and a variety of other devices. In heavy vehicle automobile, compressed air is also used for power brakes. [1]

This Air Compressor Study unit is designed to study the characteristic of a two-stage air compressor and the compressed airflow through flow arrangement.This unit is self-contained, fully instrumented, mild steel frame-mounted on raised foundation, with intercooler, air stabilizing tank and air receivers. An AC motor drives the compressor. The intercooler will provide adequate cooling to the system and is supplied with pressure and temperature measuring instruments at the inlet and outlet. With the introduction of intercooler the volumetric efficiency has been increased to 100 %.Air stabilizing tank stabilizes the flow of air which is mandatory in this work to measure the air flow rate[2] .It was found that actual volume of free air delivered by this compressor is 0.020 m3/sec with a work done of 77 N-m. Moreover it was also found that this compressor has a capacity to deliver air of about 1.02 Kg/minute, when its isothermal efficiency is 45 %.Specially designed intercooler has a capacity of heat rejection of 2.049 Kilojoules/kg.

1. Introduction

Intercooling of air compressors is necessary for an efficient process. A heat exchanger of shell and tube type particularly suitable as an intercooler between compression stages of a compressor. A characteristic of heat exchanger design is the procedure of specifying a design, heat transfer area and pressure drops and checking whether the assumed design satisfies all requirements or not. The purpose of our project is to provide an easy and efficient way to design of an air compressor test rig with intercooler. Design methodology is based on the open literature. [3]

Industrial plants use compressed air throughout their production operations, which is produced by compressed air units ranging from 5 hp to over 50,000 hp. It is worth noting that the running cost of a compressed air system is far higher than the cost of a compressor itself. The US Department of Energy (2003) reports that 70% to 90% of compressed air is lost in the form of unusable heat, friction, misuse and noise. [4]

For this reason, compressors and compressed air systems are important areas to improve energy efficiency at industrial plants. For improving efficiency compression is done in more than one stage and between each stage intercooler is provided. Intercooler improves the quality of air and reduces inlet air temperature.

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On doing this, large quantities of condensate (water) are formed. Disentrainment of liquids can be a problem in intercooler systems of compressor plants, so proper separator arrangement should be made without considerable pressure drop. In industry, reciprocating compressors are the most widely used type for air compression.

2. Intercooler

Inter-coolers are provided between successive stages of a multi-stage compressor to remove the heat of compression hence reduces the work of compression (power requirements). [5] The work of compression (power requirements) is reduced by reducing the specific volume through cooling the air. Thus intercooling affects the overall efficiency of the machine. Ideally, the temperature of the inlet air at each stage of a multi-stage machine should be the same as it was at the first stage. This is referred to as “perfect cooling” or isothermal compression. But in actual practice, the inlet air temperatures at subsequent stages are higher than the normal levels resulting in higher power consumption, as larger volume is handled for the same duty. Generally air-to-liquid intercooler intercoolers are used due to its high heat transfer rate compare to air-to-air intercoolers. Air-to-liquid intercooler usually used water as an intermediate fluid. Air-to-liquid intercoolers are usually heavier than their air-to-air counterparts due to additional components making up the system (water circulation pump, fluid, and plumbing). [6]

2.1 Function of Intercooler used in air compressor

Intercooler used in air compressor performs following functions:

1. Atmospheric air contains moisture, and furthermore, the air may pick up oil vapour as it passes through some compressors. Cooling the air down to or below its initial temperature will remove moisture down to the dew point, improving the quality of the air.
2. Another purpose of inter cooling is to improve the efficiency of compression. This is done by reducing the work of compression (power requirements).[7]
3. As the air comes out from compressor is at higher pressure as well as at higher temperature. This higher temperature may create problem for pneumatic tools, so intercoolers are used to reduce the outlet temperature of compressed air.
4. Every 40C rise in inlet air temperature results in a higher energy consumption by 1 percent to achieve equivalent output. Hence the intake of cool air improves the energy efficiency of a compressor [8].

2.2 Principle Behind Intercooling in Multistage Compression

The specific work input, w in reversible, polytrophic compression is given by equation (1)

$$w = -\int_1^2 v.dP = \left(\frac{n}{n-1}\right) P_1 v_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{(n-1)/n}\right] \quad (1)$$

Where,

P1 = the inlet pressure of the compressor

P2 = the outlet pressure of the compressor

V1 = the specific volume of air at the inlet to the compressor n = the polytrophic exponent

W = specific work input

From the above expression, it can be seen that specific work input reduces as specific volume, V1 is reduced. And we know that at a given pressure, the specific volume can be reduced by reducing the temperature[9-10]. Following Fig. 1 shows P-v diagram of polytropic compression process with intercooling which shows saving in work by using intercooler clearly.

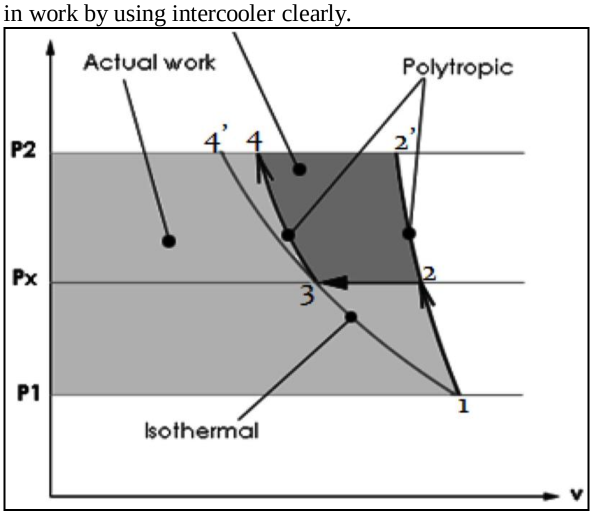

Fig: 1. P-V Diagram of Polytropic Compression Process with Intercooling

The optimal value of intermediate pressure P (location of intercooler) that yields maximum compressor work saved is given by equation (2) [11]

P2=P1P2 (2)

That means the pressure ratio of each stage should be identical to get the lowest amount of work required for air compression.

3. Objective

The main objective of our project, as the name replicates "Designing and Fabrication of Intercooler and Control of Three Phase Digitalized Reciprocating Air Compressor Test Rig with Automatic Control Drive Unit" is

A. To find out the performance of Double Stage Air Compressor.
B. To design and fabricate an Intercooler- "Shell and Tube" type for heat transfer.
C. To design and fabricate Air Stabilizing Tank.
D. To design and fabricate Electrical Panel.
E. To design and fabricate Orifice Meter.
F. To control the speed of motor and compressor with Automatic control drive unit.
G. To make electrical connections and to learn how to feed Current Transformer Coil (C.T) values in energy meter, ampere meter so as to get the output from the meter.
H. To feed numerical values in Automatic Control Drive unit for making it compactable with our test rig and to study how to operate the A.C Drive.

Based on the above given agendas we also have to calculate the following parameters.

1. To calculate the speed of the compressor **(N_2).**
2. To calculate the density of air **(ρ_a).**
3. To calculate the manometric difference **(h).**
4. To calculate the air head causing flow **(H_a).**
5. To calculate the area of orifice **(a).**
6. To calculate the coefficient of discharge **(C_d).**
7. To calculate the actual volume of free air delivered **(V_a).**
8. To calculate the mass of air supplied **(m_{air}).**
9. To calculate the volume of low pressure cylinder **(V_{Lp}).**
10. To calculate the volume of High pressure cylinder **(V_{Hp}).**
11. To calculate the theoretical volume of free air delivered **(V_{tp})**
12. To calculate the volumetric efficiency **(η_{vol})**
13. To calculate the absolute suction pressure **(P_1)**
14. To calculate the absolute delivery pressure **(P_2)**
15. To calculate the compression ratio **(r)**
16. To calculate the work input to the compressor **(W_{IN})**
17. To calculate the work done per cycle in compressing air in low pressure cylinder **(W_{LP}).**
18. To calculate the work done per cycle in compressing air in High pressure cylinder **(W_{HP}).**
19. To calculate the actual work done **(W)**
20. To calculate the Indicated power **(IP)**
21. To calculate the mass of air delivered by the compressor per minute **(m)**
22. To calculate the Isothermal work **(W_{Iso})**
23. To calculate the Isothermal power **(Iso_{po})**

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24. To calculate the isothermal efficiency **(η_{Iso})**
25. To calculate the overall isothermal efficiency **($\eta_{Iso})_{ov}$**
26. To calculate the heat rejected to the intercooler **(Q_{2-3})**
27. To check the Voltage output of all the three phases and combined phased when load is applied to the compressor **(V)**
28. To check the Ampere rating of all the three phases when load is applied to the compressor **(A)**
29. To check the Temperature output from four places
(i) Intake temperature **(T_1)**
(ii) Temperature before Intercooler **(T_2)**
(iii) Temperature after Intercooler **(T_3)**
(iv) Delivery temperature **(T_4)**
30. To check the Watt consumption of all the three phases when load is applied to the compressor **(W)**
31. To check the Power Factor of all the three phases when load is applied to the compressor, **(P.F)**
32. To check the Revolution per minute of the motor, with and without load **(R.P.M).**

4. Material and Methodology

4.1 MATERIALS: Material/Design Parameters/ Specifications

Table: 1 Material Data

S. NO	Name	Specification
1	Make of compressor	Speedways
2	Bore of high pressure cylinder of compressor	70 mm
3	Bore of Low pressure cylinder of compressor	94 mm
4	Stroke of high pressure cylinder of compressor	156 mm
5	Stroke of Low pressure cylinder of compressor	156 mm
6	Minimum rated speed of compressor	700 r.p.m
7	Maximum working pressure of compressor	12 Kg/cm^2
8	Air capacity of compressor	250 Liter
9	Diameter of orifice	21 mm
10	Diameter of motor pulley	125 mm
11	Diameter of compressor pulley	457 mm
12	Energy meter constant	1600
13	Rated speed of motor	2800 r.p.m
14	Motor horse power	3
15	Connection of motor	03Phase
16	Gate valve-(13mm)-Brass make	06 Piece
17	Vacuum pressure gauge(760 mm of Hg)	01Piece
18	Delivery pressure gauge(150 psi)	01 Piece
19	Material of shell of intercooler	Mild steel
20	Diameter of shell of intercooler	67 mm
21	Thickness of shell of intercooler	4 mm
22	Length of shell of intercooler	254 mm
23	Thickness of tube of intercooler	1.5 mm
24	Material of tube of intercooler	Mild steel
25	Total length of tube of intercooler	698 mm
26	Diameter of tube of intercooler	18.5 mm
27	Diameter of plate to be fixed on intercooler on left and right side.	67 mm
28	Material of inlet, outlet and drain pipe of intercooler	Mild steel
29	Water inlet pipe diameter of intercooler	12 mm
30	Gate valve diameter at water inlet portion of intercooler	13 mm
31	Water outlet pipe diameter of intercooler	12 mm
32	Gate valve diameter at water outlet portion of intercooler	13 mm
33	Drain pipe diameter of intercooler	12 mm
34	Drain valve diameter at drain portion of intercooler	13 mm
35	Material of drum of intercooler	Mild steel
36	Diameter of drum -1 at suction side of intercooler	67 mm
37	Height of drum -1 at suction side of intercooler	66.5 mm
38	Diameter of plate to be fixed on drum-1on upper and lower side of the drum	67 mm
39	Diameter of drum -2 at delivery side of intercooler	67 mm
40	Height of drum -2 at delivery side of intercooler	66.5 mm
41	Diameter of plate to be fixed on drum-2 on upper and lower side of the drum	67 mm
42	Insertion diameter in drum -1 for temperature reading of intercooler	6.16 mm
43	Length of insertion in drum -1 for temperature reading of intercooler	64 mm
44	Insertion diameter in drum -2 for temperature reading of intercooler	6.16 mm
45	Length of insertion in drum -2 for temperature reading of intercooler	64 mm
46	Diameter of thermocouple	6.15 mm
47	Total number of thermocouples	05
48	Length of thermocouple	125 mm
49	Thermocouple type	J-Type
50	Material of base frame	Mild steel
51	Length of base frame	2340 mm
52	Breadth of base frame	580 mm

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53	Height of base frame channel	100 mm
54	Channel designation	ISJC 100
55	Rollers fitted with channel	04 Number
56	Material of rollers	EN-8
57	Diameter of roller	50 mm
58	Length of roller	70 mm
59	Manometer	(-25)-0-(+25) mm
60	Manometer type	U tube
61	Manometer make	Acrylic
62	Manometric fluid	Water
63	Thermocouple make	J-Type
64	Total number of thermocouple	05
65	Safety valve -Brass make-13 mm	01 Piece
66	Pressure cut off switch-Spring loaded	01 piece
67	Delivery pressure gauge	01 piece
68	Delivery pressure gate valve	13 mm
69	Diameter of pipe from air stabilizing tank to low pressure cylinder	30 mm
70	Length of pipe from air stabilizing tank to low pressure cylinder	3000 mm

4.1.1. Digital Panel

For taking output data we have fixed some digital based meters, all of them are working on three phase electrical connections.

Table: 2 Digital Panel

S. No	Part Name	Phase	Pieces
1	Voltage meter	3-Phase	01 Piece
2	Temperature Meter	3-Phase	01 Piece
3	Ampere meter	3-Phase	01 Piece
4	Energy meter	3-Phase	01 Piece
5	Rotation per minute meter, (r .p. m)	1-Phase	01 Piece
6	Automatic control unit drive	3-Phase	01 Piece
7	Miniature circuit breaker-Triple pole triple throw type (T.P.T.T)	3-Phase	01 Piece
8	Miniature circuit breaker-Single pole single throw type (S.P.S.T)	1-Phase	06 Piece
9	Current transformer coils, Ratio- (5/30)	1-Phase	05 Piece
10	Light emitting diode based indicators	1-Phase	07 Piece
11	Proximity Sensor	1-Phase	01 Piece
12	ON/OFF push button	1-Phase	02 Piece
13	Contactor	3-Phase	01 Piece

4.2 Methodology

First of all, we all decided to design and fabricate a reciprocating air compressor test rig. Then part list was made and during that time we thought that to control the speed/load input of the motor/compressor, we will not make use of old type of dynamometer, i.e. rope and brake type but we will make use of automatic control drive unit to control the speed of the compressor/motor. After purchasing of all items, a rough drawing was made, deep study was done on thermodynamics and how to design and make **shell and tube type Intercooler. Air compressor** of capacity **250** liter, **2 Horse power, 3 kilowatt** and maximum working pressure of **12kg/cm^2**was finalized for our work and the same was purchased. **Electric motor** was lying unused in our **college store**. We took the motor, but, when it was checked it was found that its **winding was short**, and then we took the motor to our local electrical shop where it was **rewinded** again. The capacity of motor is **3 Horse power, 3-phase** and **2800 r.p.m.** We started our work from frame making, which was made of **Mild Steel Channel.** Frame work of **2340 x 580 x 100 mm** was done. Below the frame, **04** rollers of diameter **50 mm** and length of **70 mm** is fixed for moving the whole apparatus. Material used for roller making was **EN-8.**Then **intercooler** was designed and fabricated for increasing the volumetric efficiency of the air compressor. Intercooler work was based on **shell and tube type** of **heat exchanger** as already stated. Material for Intercooler was **Mild Steel.** Detailed drawing was made from which the following points are summarized.

(Please refer to drawing sheets for more details)

1. Firstly **Shell** size was determined which comes out **diametrically** to be **67 mm and longitudinally 254 mm** and **thickness** of shell is **4 mm.** The shell work was done on lathe machine**. 03** holes of **diameter 18.5 mm** were done upon the shell, **02** on its **top** and **01** on its **bottom** side for making continuous flow of water inside the intercooler**.** The shell is hollow from inside.
2. Then **Tube** size and length was determined. **Diametrically** the size of the tube is **18.5 mm.** The **total length** of the tube starting from low pressure cylinder to high pressure cylinder, by passing through the intercooler was found out to be **698 mm.** The tube is **2 mm thick**.
3. Now **Drum** size was determined which comes out **diametrically** to be **67 mm** and **height** of **66.5 mm**. Drums were made on lathe machine. The drum is hollow from inside.
4. Now **06** pieces of **round plates** having **diameter** of **67 mm** and **thickness** of **2 mm** were made. A hole of **18.6 mm diameter** was made in the **centre** of these plates so as to pass the tube through it. These round plates were welded at the following places:
    - At the **upper** face of **drum**-1.
    - At the **lower** face of **drum**-1.
    - At the **upper** face of **drum**-2
    - At the **lower** face of **drum**-2.
    - At the **left** face of **intercooler**.
    - At the **right**s face of **intercooler**.
5. Two **small pipes** were made which were inserted on the top side of drum-1 and drum-2 plates at an angle of **30^0,** having **diameter** of **6.16 mm** and **length** of **64 mm** through which **thermocouples** of size **6.15 mm** are to be inserted for measuring the temperatures.
6. Now **02** tubes having **diameter** of **18.5 mm** and **length** of **43 mm** were made. These tubes are to be welded at

the **bottom side** of **both** the **drums** upon the round plates which were made earlier. These tubes are to be inserted upon the inlet portion of low pressure cylinder and high pressure cylinder.

7. Now again **02** tubes of **18.5 mm diameter** were taken and **02 lengths** of **83 mm** were cut. Each tube is to be fitted upon the drum and is to be welded upon the round plates.
8. Then comes the work of shell. As the shell was made earlier, now round plates which were made earlier is taken and is welded on the drum, one on its left side and one on its right side.
9. Now a tube of size **18.5 mm diametrically** and **length** of **457.2 mm** is taken. It is made to pass through the shell. From both sides of the plates this tube is welded and it is also welded with the tube coming out from both the drums at right angles.
10. After this whole process now **03** bends at a right angle were made. These are to be fitted at inlet, outlet and at drain portion of the shell .Size of the tube taken for these bends is **12 mm diametrically** and **02 mm thick**. Length of the bend is **52 mm** and breadth is **35 mm** .Threads of mm size were made upon the bend so as to tight gate valves upon it for regulating the flow of water.
11. Now the bends are welded upon the shell, with gate valves of **13 mm diameter** fixed upon the bends.
12. Now the intercooler is fixed upon the compressor and water is made to flow from it. Compressor is also switched on so as to check the leakage if any present inside the intercooler. But with god grace there was no leakage. Neither air was leaking nor was water leaking.

During the suction stroke the air from the atmosphere is sent into the low pressure cylinder. During compression, air is sent to high pressure cylinder through intercooler. The flow of air in the pipe line from the atmosphere to the low pressure cylinder is not uniform (i.e. intermittent) due to the suction of air which takes place in the alternative strokes. To measure the flow of air, the flow must be uniform across the orifice. Otherwise the manometer reading will fluctuate. Hence an air stabilizing tank was made which is introduced between the orifice meter and the low pressure cylinder. This stabilizes the flow of air between the air filter and the stabilizing tank. While connecting the pipe line and the stabilizing tank we have to see that they are connected in diametrically opposite direction .However in practical application intercooler and air stabilizing tank is not fitted with the compressor, but for experimental study work we have to fix it with the compressor. The size of the stabilizing tank is **280 x355 x 406 mm**. In front of the stabilizing tank rubber is attached with the frame of size **406 x 280 mm** so as to create a vacuum during the suction stroke. An iron sheet of size **406 x 280 mm** is attached in front of the tank. Material used for making of tank is mild steel. ***(Please refer to drawing sheets for more details)***

On the upper side of the air stabilizing tank **orifice meter** of **28 mm** diameter if fitted. Below the suction tank a delivery pipe of **30 mm** diameter is attached which is to be connected to the suction side of low pressure cylinder. For making of orifice meter the following procedure was adopted.

(Please refer to drawing sheets for more details)

1. Firstly a Mild steel pipe of **28 mm** diameter was taken. ***(Major pipe).***
2. Then **01** pieces of ***(Major pipe)*** of **28 mm diameter** and **66 mm** length and was cut. ***(Major pipe-1).***
3. Upon this pipe, ***(Major pipe-1),*** from a length of **25.17 mm** a hole of diameter **15.25 mm** is made, for insertion of small pipe, ***(Minor pipe-1)*** which is to be connected to manometer.
4. Then **01** pieces of ***(Minor pipe-1)*** of **15.25 mm** in **diameter** and **49.50 mm** in **length** was cut. This ***(Minor pipe-1)*** is welded at right angles upon the holes with the ***(Major pipe-1)***.
5. Then **01** plates of **diameter 75 mm** and **thickness** of **4.70 mm** was made on lathe and hole of **28 mm** was made in the centre of the plates. ***(Base plate-1).***
6. Now at the outer skirts of this plate, ***(Base plate-1),***03 holes of **10 mm diameter** at an angle of $60^0$is done for joining of plates, with rubber gasket and with centre plate of 1.70 mm diameter.
7. Upon this plate, ***(Base plate-1),*** the above made pipe of **28 mm diameter ;*(Major pipe-1)*** is welded upon the centre hole.
8. In this way 02 pieces are made, ***(Major pipe-1 and Major pipe-2).***
9. Then **02** rubber gasket ***(Rubber gasket-1-2)*** of **diameter 75 mm** and **thickness of 2.70 mm** were made and hole of **28 mm** was made in the centre of the gaskets. 03 holes of **10 mm diameter** at an angle of $60^0$is done upon the gasket for joining them with ***(Major pipes-1-2)***.
10. Now **01** more plate is made of **75 mm** in **diameter** but with a **thickness** of 1**.75 mm** and hole of **07 mm** was made in the centre of the plate. 03 holes of **10 mm diameter** at an angle of $60^0$is also done upon this small plate ***(centre plate)*** for joining of this plate with ***(rubber gasket-1-2)*** and with ***(Base plate).***
11. Now lastly all the parts are assembled, upon the ***(Base plate-2)*** of 4.70 mm, **(rubber gasket-2)** is placed, upon the ***(rubber gasket-2), (centre plate)*** of 1.70 mm is placed, upon the ***(centre plate)*** again ***(rubber gasket-1)*** is placed and lastly upon the rubber gasket ***(Base plate-1)*** of 4.70 mm is placed with all the holes matching and bolted all together with **10 mm** nut and bolt.

On the suction side we have fixed negative pressure gauge of maximum capacity of **760 mm of Mercury**, **(Hg).** To measure the maximum amount of suction pressure we have to close the suction side of the orifice meter for a few seconds. By closing the orifice from the top side we can see that the maximum suction pressure rises to **100 mm of mercury (Hg),** but precaution should be taken that we should not close the top side of the orifice meter for a long time of duration. Thermocouple is also attached here for measuring the temperature of air.Positive pressure gauge is fitted on the delivery side of high pressure cylinder whose maximum capacity is **150 psi** along with thermocouple.

A thermocouple is also attached with main frame so as to know the room temperature also. Special guard is attached with the compressor to safeguard the wires and electrical connections.

Specially acrylic make manometer is fitted with the orifice meter to measure the air flow. It **is u tube** based and working fluid is **water**. The range of manometer is **(-25)-0-**

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(+25) mm. Left side of orifice meters ***minor pipe*** is attached with left side pipe of manometer and right side of orifices meter ***minor pipe*** is attached with right side pipe of manometer. One **safety valve** is fixed at the final output/discharge line of the compressor and one spring **loaded pressure cut off switch** is attached with the compressor so that the motor is switched off automatically if the compressor is filled at our prescribed limit.

An air damper is needed on both sides of the compressor, i.e. on suction side and on delivery side as the suction and delivery pressure gauges fluctuates while compressor is running. The basic reason of fluctuation of needles of gauges is because of the fact that during fraction of a second both, suction stroke and delivery stroke takes places which causes fluctuation in the gauges.To remove this effect we have fitted two gate valves of **13 mm** on delivery side of the compressor, from which we can create a damping effect and can get the needle of the pressure gauge stabilized to a large extend.

Now comes the work of electric panel. An electric panel was made with wooden board of size **2440 x 1220 x 10 mm** .Pieces were cut from the board to make a panel of size **915 x 610 x254 mm.** Digital meters like energy meter, voltage meter, ampere meter, temperature meter and r.p.m meter were fitted on the panel. Automatic control drive unit, miniature circuit breaker of triple pole triple throw and single pole single throw along with current transformer coils, light emitting diodes (Indicators), were attached with the meters. Electric supply is given to these meters via 3 phase motor. From voltmeter we can find out different voltages either by combining individual lines or by combination of the two phases. From ampere meter we can find out the current at line-1, line-2 and line-3. From the r.p.m meter we can find out the r.p.m of the pump. We use 7 indicators to know the supply status of all the meters. Automatic control drive is fitted from where we can change the r.p.m of the motor and can apply load on the pump. Proximity switch is fixed in front of the motor so as to know the r.p.m of the motor.

This was not the end for us. When we ran the compressor for two hours, after completion of two hours **tingling voices** were started coming out of the compressor. Then after a long discussion with our project head it was decided to open the head of the compressor, when the head was open it was found that there as a gap of **0.125 micron** in the cut given to the crankshaft main bearing point, from where the voice was coming during the running time. Then head was assembled again and it was taken back to the supplier, then new head was taken and got it fitted upon the receiver. After that it was made to run continuously for 5 hours. After that we were satisfied for our work done.

Then readings were taken for the given objectives. Lastly paint work was done to give a good and charming finish to the apparatus. Normal paint was not done but we had purchased paint of 2K company for giving it more finish to our work. After paint work was over, Lacquer was sprayed upon the whole apparatus with paint gun for shining.

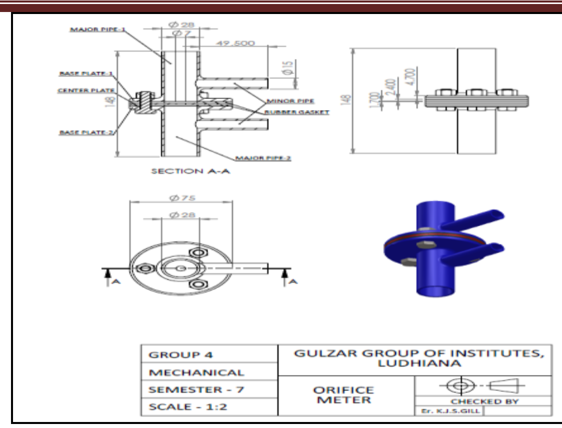

Fig: 2. Sheet #1 Orifice Meter

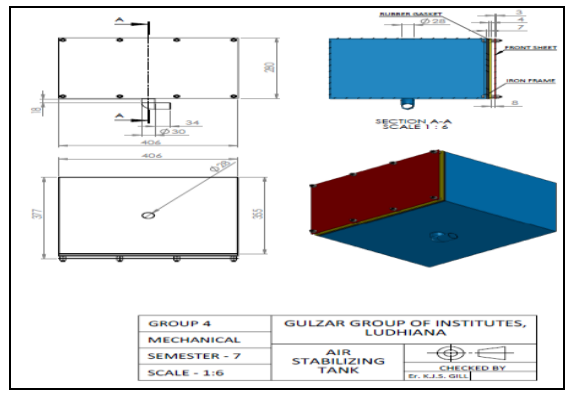

Fig: 3. Sheet # 2 Air Stabilizing Tank

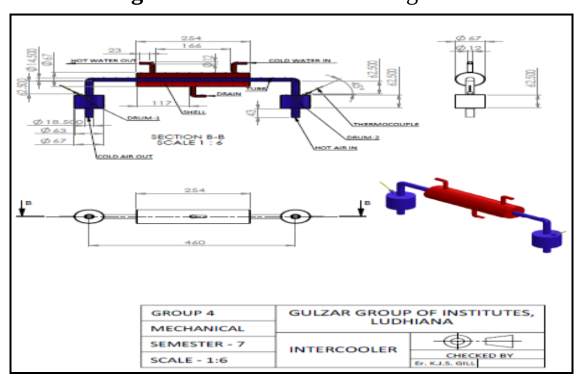

Fig: 4. Sheet # 3 Intercooler

5. Experimental Setup

Fig: 5. Experimental Setup

6. Results and Calculations

1. To calculate the Speed of the Compressor, (N_2).

$D_1 \times N_1 = D_2 \times N_2$

$$N_2 = \frac{D1 \times N1}{D2}, = \frac{152 \times 2800}{457}$$

= 931 Revolution per minute

2. To calculate the Density of air, (ρ_a).

$$\rho_a = \frac{Pa}{Ra \times Ta}$$

Pa = atmospheric pressure, = 1.013×10^5 N/m^2
R_a = Universal gas constant, = 287 J/kg
T_a = Room temperature, = 20^0 Celcius

$$= \frac{1.013 \times 100000}{287 \times (273+20)}$$

Therefore, **ρ_a= 1.20 kg/m^3**

3. To Calculate the Manometric Difference, (h).

h = h_1-h_2, = 20-19
h = 0.01 meter of water

4. To calculate the air head Causing Flow, (H_a).

$$H_a = \frac{h \times (\rho w - 1)}{\rho a}$$

ρ_w = density of water, = 1000 kg/m^3,

$$= \frac{0.01 \times (1000-1)}{1.293}$$

H_a = 7 Meter

5. To calculate the area of orifice, (a).

$$a = \frac{\pi}{4}(d)^2, = \frac{3.14}{4}(0.021)^2$$

a = 3.4 6x 10^{-4} m^2

6. To calculate the Coefficient of Discharge, (C_d).

C_d = 0.65

7. To calculate the Actual Volume of free air Delivered, (V_a).

V_a = C_d x a 2g x Ha, = 0.65 x 3.46 x 10^{-4} x 2 x9.81 x 7
V_a = 0.020 m^3/second

8. To calculate the Mass of air Supplied, (m_{air}).

m_{air} = ρ_a x V_a, = 1.20 x 0.034 , = 0.040 kg/second

9. To calculate the volume of Low Pressure Cylinder, (V_{Lp})

$$V_{Lp} = \frac{\pi}{4}(D_{LP})^2 \times L_1, = \frac{3.14}{4}(0.094)^2 \times 0.156$$

V_{Lp}= 1.08 x 10^{-3}m^3

10. To calculate the volume of High Pressure Cylinder, (V_{Hp})

$$V_{Hp} = \frac{\pi}{4}(D_{HP})^2 \times L_1, = \frac{3.14}{4}(0.070)^2 \times 0.156$$

V_{Lp}= 6.0 x 10^{-4}m^3

11. To calculate the Theoretical volume of free Air Delivered /Theoretical Volume, (V_{th})

$$V_{th} = \frac{VLp \times N2}{60}, = \frac{0.00108 \times 931}{60}$$

V_{th} = 0.020 m^3/sec

12. To calculate the Volumetric Efficiency, (η_{vol})

$$\eta_{vol} = \frac{Va}{Vth}, = \frac{0.020}{0.020} \times 100\ \%$$

η_{vol} = 100 %

13. To calculate the Absolute Suction Pressure, (P_1)

$$P_1 = 100 \text{ mm of Hg}, = 760-100, = 660 \text{ mm of Hg}, = \frac{660}{760}$$

P_1 = 0.86 bar

14. To calculate the Absolute Delivery Pressure, (P_2).

$$P_2 = 760 + 2.5\text{Inch of Hg} \times 25.400, = \frac{823}{760}$$

P_2 = 1.08 bar

15. To calculate the Compression Ratio, (r).

$$r = \frac{P2}{P1}, = \frac{1.08}{0.86}$$

r = 1.2

16. To calculate the Work Input to the Compressor, (W_{IN})

$$W_{IN} = \frac{3600 \times 10 \times 1000}{t \times \text{Energy meter constant}},$$

$$= \frac{3600 \times 10 \times 1000}{60 \times 3600}$$

W_{IN} = 375 watt

17. To calculate the work done per cycle in compressing air In Low Pressure Cylinder, (W_{LP}).

$$W_{LP} = \frac{n}{n-1} \times P_1V_1 \left[\frac{P2}{P1}^{(n-1)/n} - 1 \right],$$

$$= \frac{1.2}{0.2} \times 0.86 \times 1.08 \times 10^{-3} \left[\frac{1.08}{0.86}^{(0.16)} - 1 \right]$$

$= 2.06 \times 10^{-4} \times 10^5$

W_{LP} = 20.6 N-m

18. To calculate the work done per cycle in compressing air in High Pressure Cylinder, (W_{HP})

$$W_{HP} = \frac{n}{n-1} \times P_2V_2 \left[\frac{P3}{P1}^{(n-1)/n} - 1 \right] = \frac{1.2}{0.2} \times 1.08 \times 6.0 \times 10^{-4} \left[\frac{2}{0.86}^{(0.16)} - 1 \right]$$

$= 5.62 \times 10^{-4} \times 10^5$

W_{HP} = 56.2 N-m

19. To calculate the Actual Work Done (W)

W = W_{LP} + W_{HP}, = 20.6 + 56.2 , W= 76.8 N-m.
W =7.68 X 10^{-4} Joules/cycle

20. To calculate the Indicated Power (I.P)

I.P $= \frac{W \times N2}{60}$,

$= \frac{0.000768 \times 100000 \times 931}{60}$

= 1191 watt

I.P = 1.20 Kilo watt

21. To calculate the mass of air delivered by the compressor Per Minute, (m)

m $= \frac{P1\,V1}{RT1}$, $= 0.86 \times 10^5 \times 1.08 \times 10^{-3}/287 \times 293$

m = 1.02 kg/minute

22. To calculate the Isothermal Work, (W_{Iso})

$W_{Iso}=P_1V_1\,[\log_e \frac{P3}{P1}]$, $= 0.86 \times 1.08 \times 10^{-3}[\log_e(\frac{2}{0.80})]$,

$= 3.40 \times 10^{-4}$ joule/cycle $\times 10^5$

W_{Iso}=34 N-m.

23. To calculate the Isothermal Power, (Iso_{po})

$Iso_{po} = \frac{WIso \times N2}{60}$, $= \frac{34 \times 931}{60}$

Iso_{po}= 527.56 watt

24. To calculate the Isothermal Efficiency, (η_{Iso})

$\eta_{Iso} = \frac{Isopo}{I.P}$, $= \frac{528}{1191} \times 100$,

η_{Iso} = 45 %

25. To calculate the Overall Isothermal Efficiency, $(\eta_{Iso})_{ov}$

$(\eta_{Iso})_{ov} = \frac{Isopo}{B.P\ of\ motor} = \frac{528}{3 \times 746.} \times 100$

$(\eta_{Iso})_{ov}$ = 25 %

26. To calculate the heat Rejected to the Intercooler, ($Q_{2\text{-}3}$)

$Q_{2\text{-}3}=m_a \times c_p \times (T_2 - T_3)$, $= 1.02 \times 1.002 \times (36\text{-}34)$

$Q_{2\text{-}3}$ = 2.049 kilojoules / kg.

27. To check the Voltage output of all the three phases and combined phased when load is applied to the compressor (V)

Voltmeter reading (V) =

S. No	φ- 1	φ -2	φ - 3	φ - 1+2	φ - 2+3	φ - 3+1
1.	242.3	230.9	235.4	407.5	410.4	409.1

28. To check the Ampere rating of all the three phases when load is applied to the compressor (A)

Ampere meter Reading (A) =

S. No	φ- 1	φ - 2	φ - 3
1.	2.34	2.46	2.1

29. To check the Temperature output from four places

1. Intake temperature (T_1)=24^0 Celsius
2. Temperature before intercooler (T_2)=36^0 Celsius
3. Temperature after intercooler (T_3)=33^0 Celsius
4. Delivery temperature (T_4)=30^0 Celsius
5. Normal air temperature (T_5)=20^0 Celsius

30. To check the Watt consumption of all the Three Phases When load is applied to the Compressor (W)

W=

S.No	φ- 1	φ – 2	φ - 3
1.	802	140	124

31. To check the Power factor of all the Three Phases When Load is Applied to the Compressor, (P.F) =

S.No	φ- 1	φ – 2	φ - 3
1.	**0.499**	**0.412**	**0.09**

In this project we have studied about multistage air compressor & main components used in air compression system like air stabilizing tank, orifice meter and intercooler. Full study was done on compressors, its types, its working, and effect of intercooler for increasing the efficiency of the compressor. Multistage air compressor was taken for study and experimental work. Following points are concluded from this very work.

7. Conclusion

1. The Department of Energy (2003) reports that 70 to 90 % of compressed air is lost in the form of unusable heat, friction, misuse and noise. For this reason, compressors andcompressed air systems are important areas to improve energy efficiency at industrial plants. For improving efficiency compression is done in more than one stage and between each stage intercooler is provided. Intercooler improves the quality of air and reducesinlet air temperature. On doing this large quantities of condensate (water) are formed .Distrainment of liquids can be a problem in intercooler systems of compressor plants, soproper separator arrangement should be made without considerable pressure drop. In industry, reciprocating compressors are the most widely used type for air compression.
2. We have also studied about initial design consideration of intercooler in which there is given practical guidelines about the fluid stream allocation, tube material selection forbetter heat transfer & corrosion resistance, tube layout patterns, tube pitch, baffles,baffles spacing, baffles cut & tube passes**.** Moreover it is to clarify from the results that we have increased the **volumetric efficiency** of the compressor up to **100 %** by the introduction of **intercooler** between the two heads of the compressor, although its **isothermal** efficiency is less than **50 %.**
3. During the suction stroke the air from the atmosphere is sent into the low pressure cylinder. During compression, air is sent to high pressure cylinder through intercooler. The flow of air in the pipe line from the atmosphere to the low pressure cylinder is not uniform (i.e. intermittent) due to the suction of air which takes place in the alternative strokes. To measure the flow of air, the flow must be uniform across the orifice. Otherwise the manometer reading will fluctuate. Hence an air stabilizing tank is introduced between the orifice meter and the low

pressure cylinder. This stabilizes the flow of air between the air filter and the stabilizing tank. While connecting the pipe lineand the stabilizing tank we have to see that they are connected in diametrically opposite direction .However in practical application intercooler and air stabilizing tank is not fitted with the compressor, but for experimental study work we have to fix it with the compressor.

4. An air damper is needed in both sides of the compressor, ie. On suction side and on delivery side as the suction and delivery pressure gauges fluctuates while compressor is running. The basic reason of fluctuation of needles of gauges is because of the fact that during fraction of a second both, suction stroke and delivery stroke takes places which causes fluctuation in the gauges. Positive pressure gauge is fitted on the delivery side whose maximum capacity is **150 psi.** To remove this effect we have fitted two gate valves of **13mm** on delivery side of the compressor, from which we can create a damping effect and can get the needle of the pressure gauge stabilized to a large extend.

5. On the suction side we have placed negative pressure gauge of maximum capacity of **760 mm of Mercury**, **(Hg).** To measure the maximum amount of suction pressure we have to close the suction side of the orifice meter for a few seconds. By closing the orifice from the top side we can see that the maximum suction pressure rises to **100 mm of mercury (Hg),** but precaution should be taken that we should not close the top side of the orifice meter for a long time of duration.

8. Summary

The aim for the current study is to replace the single acting compressor by double acting compressor with intercooler fitted so as to increase the volumetric efficiency which generates 12 kg/cm^2 of compressed air .The experimental study is focused on a compressor purchased by us of SPEEDWAYS Company. Air stabilizing tank was fitted so as to measure the constant air flow rate by manometer.

Compressed air is used in air refrigeration, cooling of large building, for cleaning purposes, blast furnaces, bore wells, spray painting, in super charging IC engines and gas turbines, starting of IC engines, fuel atomizers, compressed air is widely used in braking system of automobiles, railway coaches, wagons etc. and the list is endless where the compressed air is used. In fact today, we find it is extensively used in all fields of application due to Wide availability of fresh air. Compressibility, Easy transportability of compressed air in pressure vessel, containers and long pipes. Fire – proof characteristics of the medium. High degree of controllability of pressure. The detail study of different types of compressor is very much essential. The current study is focused at the study of double acting reciprocating compressors. The advantage of double acting compressor is that it delivers almost double compressed air (almost in half time) which saves time and money of the user.

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